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RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS AT A MACH NUMBER OF 2.01 OF TWO
 CRUCIFORM MISSILE CONFIGURATIONS HAVING 70° DELTA WINGS
 WITH LENGTH-DIAMETER RATIOS OF 14.8 AND 17.7 WITH
 SEVERAL CANARD CONTROLS

By M. Leroy Spearman and Ross B. Robinson

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
August 30, 1954



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SUMMARY

Further tests have been made at a Mach number of 2.01 of the fineness-ratio-14.8 missile configuration of NACA RM L53114. In the present investigation, this configuration and a configuration with a length-diameter ratio of 17.7 were equipped with 60° and 70° delta canard controls of area approximately twice that tested previously. The purpose of these tests was to determine the combined effect of canard size on pitching effectiveness and on interference losses at the wing.

Wing efficiency, as indicated by the pitching moments of the body-wing configurations, with and without canard controls, decreased as control size was increased, particularly at low angles of attack, or as body length was shortened. In neither case, however, were the interference effects such as to impair the linearity of the variation of the pitching moments with angle of attack. A substantial improvement in angle of trim was indicated for the shorter configuration by moving the center-of-gravity location rearward from the test moment reference point at 58 percent of the body length to 62 percent of the body length. For this condition, the rate of change of trim angle of attack with canard deflection was about twice that previously obtained for the missile configuration with small (10 percent of the wing area) 70° canard controls and with a length-diameter ratio of 14.8.

INTRODUCTION

A program for the development of cruciform missile configurations with canard controls has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel. The basic models employed surfaces of delta

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plan form with 70° swept leading edges for the wings and for the all-movable canard controls. The effects of control deflection and body length on the aerodynamic characteristics of the missile at Mach numbers of 1.61 and 2.01 are shown in references 1, 2, and 3. The characteristics of the cruciform canard arrangement as well as some very small span wing-body configurations at a Mach number of 1.41 are presented in reference 4. The characteristics of two of the cruciform canard arrangements in combined pitch and sideslip at a Mach number of 2.01 are presented in reference 5.

The results of reference 1 have shown that the use of a long body and a long canard-control moment arm for the purpose of reducing the canard wake effects and increasing the canard pitching-effectiveness may be unsatisfactory since the unstable pitching-moment characteristics of the long body would limit the usable angle of attack that might be obtained without the occurrence of second trim points or missile tumbling. In fact, the shortest missile considered in reference 1 (length-diameter ratio of 14.8) indicated a higher usable variation of trim angle of attack with canard control deflection than any of the longer body missiles and yet did not indicate the appearance of any serious interference effects of the canard control on the wing efficiency. It was then thought desirable to increase the canard control size in an effort to establish to what limit the controllability might be increased before the onset of any serious interference effects. To this end, an investigation was undertaken in which a 60° and a 70° delta canard having about twice the area of the original canard were installed on the short missile body (length-diameter ratio of 14.8) and also on a missile of intermediate length (length-diameter ratio of 17.7). It was expected that these larger controls would have greater pitching effectiveness than the original control but should also tend to increase the interference losses at the wing. The present paper contains the results of the investigation of the aerodynamic characteristics at a Mach number of 2.01 of the two cruciform wing missiles equipped with the larger canard controls and compares the result with that obtained previously with a smaller control.

SYMBOLS

The results of the tests are presented as standard NACA coefficients of forces and moments referred to the body-axis system (fig. 1) with the moment reference point for all configurations located 6.25 body diameters forward of the base of the body.

C_N normal-force coefficient, N/qS

C_C chord-force coefficient, C/qS

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C_m	pitching-moment coefficient, $M'/qS\bar{c}$
C_l	rolling-moment coefficient, L'/qSb
L/D	lift-drag ratio, $\frac{C_N \cos \alpha - C_C \sin \alpha}{C_N \sin \alpha + C_C \cos \alpha}$
N	normal force
C	chord force
M'	pitching moment
L'	rolling moment
N'	yawing moment
Y	lateral force
q	free-stream dynamic pressure
S	total wing area resulting from extending the wing leading and trailing edges to the body center line
\bar{c}	wing mean aerodynamic chord
d	diameter of body
b	span of wing
l	length of body
x	longitudinal distance from nose
M	Mach number
α	angle of attack, deg
β	angle of sideslip, deg
δ_H	horizontal-canard deflection angle, deg
η_W	wing efficiency factor, $\frac{C_{m_{BWC}} - C_{m_{BC}}}{C_{m_{BW}} - C_{m_B}}$

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$\frac{\Delta C_m}{\Delta \delta_H}$	increment of pitching-moment coefficient due to horizontal canard deflection
$\alpha_{\delta_{trim}}$	rate of change of angle of attack with horizontal-canard deflection at $C_m = 0$, $(d\alpha/d\delta_H)_{C_m = 0}$
$\frac{S_C}{S_W}$	ratio of exposed horizontal canard area to exposed wing area

MODEL DESIGNATIONS

B	body
BC	body—canard-control combination
BW	body-wing combination
BWC	body—wing—canard-control combination

MODELS AND APPARATUS

Sketches of the models tested together with pertinent dimensions and designations are presented in figure 2. Details of the canard controls and wing surfaces are presented in figure 3. The geometric characteristics of the models are presented in table I.

The body of the model was composed of a parabolic nose followed by the frustum of a cone which was faired into a cylinder. The body length was varied through the use of different lengths of the cylindrical portion, with resulting body length-diameter ratios of 14.8 and 17.7. The canard surfaces and both pairs of wings had delta plan forms with hexagonal sections. The wings, vertical canards, and two of the horizontal canards tested had 70° swept leading edges. An additional horizontal canard having 60° swept leading edges was also tested. Ratios of canard exposed area to wing exposed area were 0.05 and 0.20 for the 70° delta control and 0.17 for the 60° delta control. Deflections of the horizontal canard were set manually. The vertical canard deflection was 0° for all tests. The large 70° and the 60° canard controls were tested with both the long and short bodies ($l/d = 17.7$ and 14.8) while the small 70° canard control was tested only with the short body ($l/d = 14.8$). All components of the model were removable so that tests of various combinations of components could be made.

Force measurements were made through the use of a six-component internal strain-gage balance. The angle-of-attack range was from 0° to about 28° and the angle-of-sideslip range from 0° to about -10° .

TESTS, CORRECTIONS, AND ACCURACY

Tests

The conditions for the tests were:

Mach number, M	2.01
Reynolds number, based on wing M.A.C.	3.47×10^6
Stagnation pressure, atm	1.0
Stagnation temperature, $^\circ\text{F}$	110

The stagnation dewpoint was maintained sufficiently low (-25°F or less) so that no adverse condensation effects were encountered.

Corrections and Accuracy

The angles of attack and sideslip were corrected for the deflection of the balance and sting under load. The Mach number variation in the test section was approximately ± 0.01 and the flow-angle variation in the vertical and horizontal planes did not exceed about $\pm 0.1^\circ$. No corrections were applied to the data to account for these flow variations. The base pressure was measured and the chord force was adjusted by equating the base pressure to the free-stream static pressure.

The estimated errors in the individual measured quantities are as follows:

C_N	± 0.004
C_C	± 0.002
C_m	± 0.0004
C_l	± 0.0004
α , deg	± 0.1
β , deg	± 0.1
δ_H , deg	± 0.1

RESULTS AND DISCUSSION

The aerodynamic characteristics in pitch for the component parts of various configurations are presented in figure 4. The estimated variation of C_N and C_m with α for the body alone were obtained by the method of Allen (ref. 6). The estimated variations for the body-wing (BW) and the body-control (BC) configurations were obtained through the use of references 7 and 8 in conjunction with reference 6 in a manner described in reference 2. For the complete model (BWC), the estimated variations were obtained by combining the estimated control increments with the body-wing results disregarding interference effects, that is,

$$[(BC - B) + BW] = BWC.$$

The effects of canard-control deflection on the aerodynamic characteristics in pitch for the various complete model configurations are presented in figure 5. For the shorter body configuration, there is an increase in the stability and in the linearity of the variation of C_m with α as well as a decrease in the pitching effectiveness of the canard control. As would be expected, the shorter body configuration with the small 70° canard control (fig. 5(c)) has the greatest stability and the lowest control pitching effectiveness because of its shorter moment arm and smaller control area.

Changes in canard-control size or body length have little effect on the L/D ratios throughout the angle-of-attack range (fig. 6).

The wing efficiency (fig. 7) as indicated by the pitching moments of the body-wing configurations with and without the canard control decreases, particularly at low angles of attack, as the control size was increased or as the body was shortened.

The variation of the canard control pitching-moment effectiveness with angle of attack for the various configurations is shown in figure 8. The value for the 70° control having an area ratio $S_C/S_W = 0.10$ was obtained from reference 1. The estimated values at $\alpha = 0^\circ$ were obtained by multiplying the theoretical lift-curve slope obtained by the method of reference 9 for an isolated wing having the plan form of the exposed canard surfaces by the distance from the 0.67 root-chord point of the exposed canard to the model center of gravity. The estimates are in good agreement with the experimental results.

In order to determine the maximum obtainable trim angle of attack without encountering second trim points for any canard control deflection in this angle-of-attack range, the center-of-gravity location of the shorter body configuration with the 60° control ($S_C/S_W = 0.17$) was shifted

rearward from $x/l = 0.58$ to $x/l = 0.62$. For this center-of-gravity location (fig. 9), calculations indicate that a trim angle of attack of about 13° would be expected for a canard-control deflection of 9.5° . The resulting usable value of $\alpha_{\delta_{trim}}$ of about 1.4 is nearly twice the maximum usable $\alpha_{\delta_{trim}}$ of 0.74 obtained with the same configuration equipped with a 70° delta control having an area 0.10 the wing area (ref. 1).

The effect of body length on the induced lateral characteristics resulting from a 10° deflection of the large 70° canard control are shown in figure 10. The induced effects appear to be slightly greater for the longer body configuration.

CONCLUDING REMARKS

The results of the investigation of the aerodynamic characteristics at a Mach number of 2.01 of two cruciform canard-type missiles having body fineness ratios of 14.8 and 17.7 with 70° delta wings and several different canard controls have indicated that, for a center-of-gravity location at 62 percent of the body length, a maximum usable value of $\alpha_{\delta_{trim}}$ (rate of change of trim angle of attack with canard deflection) of 1.4 might be obtained for the shorter body configuration with a 60° delta canard control having an area 0.17 of the wing area. This value of $\alpha_{\delta_{trim}}$ is about twice that obtained previously for this missile configuration equipped with a smaller 70° delta canard control having an area 0.10 of the wing area. Although the wing efficiency, as indicated by the pitching moments of the body-wing configurations with and without the canard control, decreases as the control size was increased or as the body length was shortened, there were still no serious interference effects such that the linearity of the pitching moment with angle of attack would be impaired.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 28, 1954.

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1. Spearman, M. Leroy: Aerodynamic Characteristics in Pitch of a Series of Cruciform-Wing Missiles With Canard Controls at a Mach Number of 2.01. NACA RM L53I14, 1953.
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5. Spearman, M. Leroy, and Driver, Cornelius: Wind-Tunnel Investigation at a Mach Number of 2.01 of the Aerodynamic Characteristics in Combined Pitch and Sideslip of Some Canard-Type Missiles Having Cruciform Wings and Canard Surfaces With 70° Delta Plan Forms. NACA RM L54F09, 1954.
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8. Kaattari, George E., Nielson, Jack N., and Pitts, William C.: Method for Estimating Pitching-Moment Interference of Wing-Body Combinations at Supersonic Speeds. NACA RM A52B06, 1952.
9. Ribner, Herbert S., and Malvestuto, Frank S., Jr.: Stability Derivatives of Triangular Wings at Supersonic Speeds. NACA Rep. 908, 1948. (Supersedes NACA TN 1572.)

TABLE I
 GEOMETRIC CHARACTERISTICS OF MODELS

Cruciform wings:

Span, in.	11.85
Chord at body center line, in.	17.07
Chord at body intersection, in.	13.41
Area (leading and trailing edges extended to body center line), sq in.	104.8
Area (exposed), sq in.	64.2
Aspect ratio	1.40
Sweep angle of leading edge, deg	70
Thickness ratio at body center line	0.0147
Leading-edge section angle normal to leading edge, deg	15.6
Trailing-edge section angle normal to trailing edge, deg	7.4
Mean aerodynamic chord, in.	11.48

Canard surfaces:

Sweep angle of leading edge, deg	60
Ratio of canard exposed area to wing exposed area	0.17
Area (exposed), sq in.	11.08
Sweep angle of leading edge, deg	70
Ratio of canard exposed area to wing exposed area	0.05, 0.20
Area (exposed), sq in.	2.95, 12.84

Bodies:

Maximum diameter, in.	2.67
Base area, sq in.	5.58
Length, in.	39.57, 47.33
Length-diameter ratio	14.8, 17.7

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TABLE II
BODY COORDINATES IN INCHES

Body station	Radius
0 (Nose)	0
.297	.076
.627	.156
.956	.233
1.285	.307
1.615	.378
1.945	.445
2.275	.509
2.605	.573
2.936	.627
3.267	.682
3.598	.732
3.929	.780
4.260	.824
4.592	.865
4.923	.903
5.255	.940
5.587	.968
5.920	.996
6.252	1.020
6.583	1.042
11.542	1.333
47.333	1.333

} Conical section
} Cylindrical

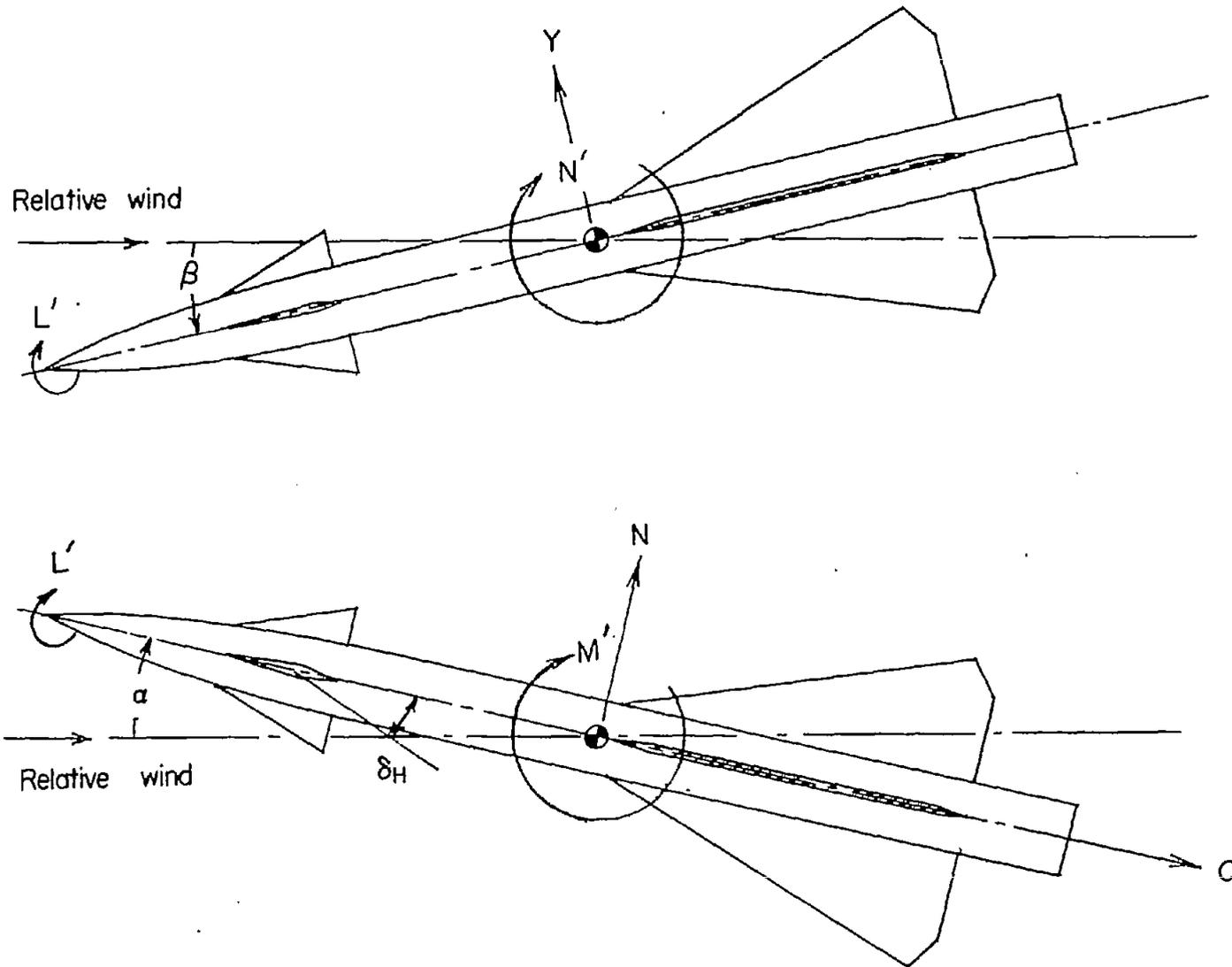
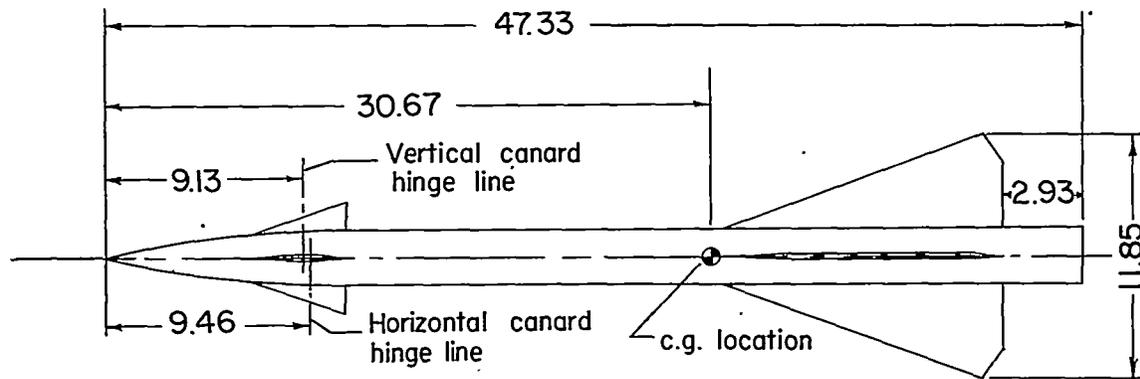
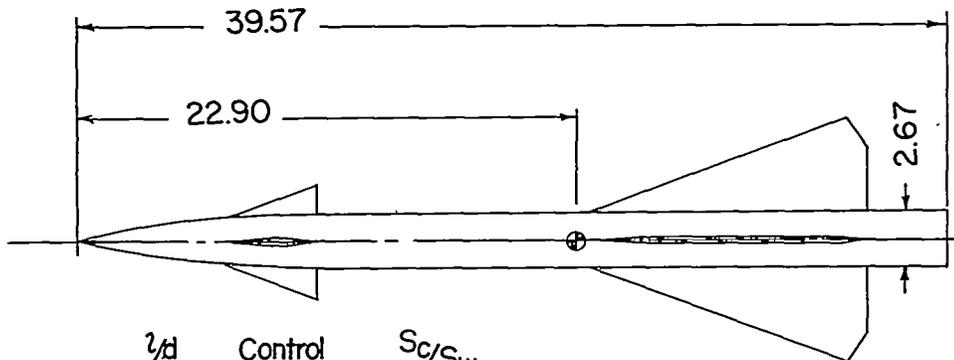


Figure 1.- System of body axes. Arrows indicate positive values.

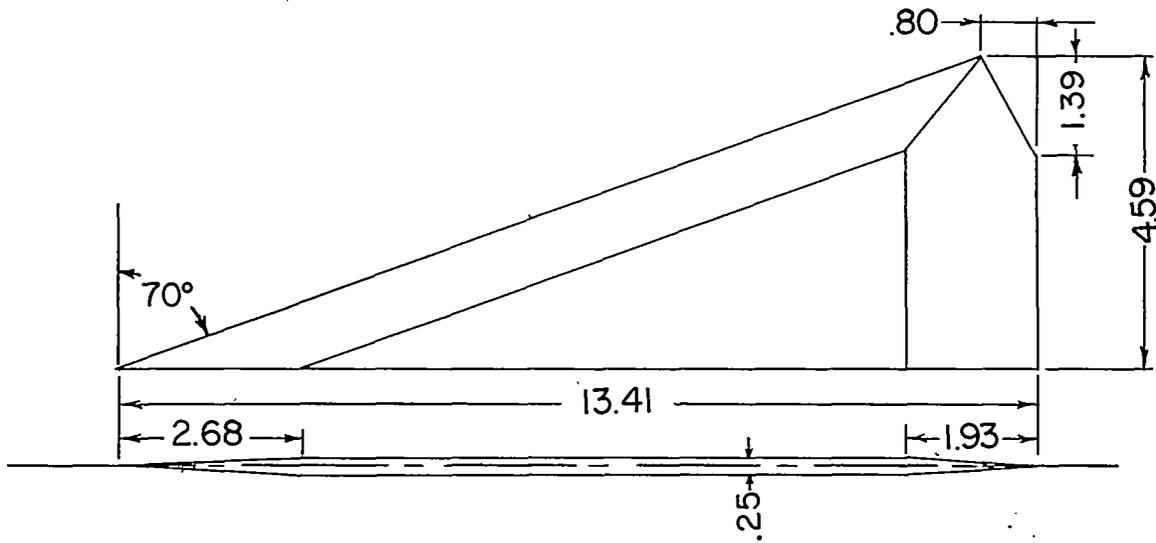


λ/d	Control	S_c/S_w
17.7	60°	0.17
17.7	Large 70°	0.20

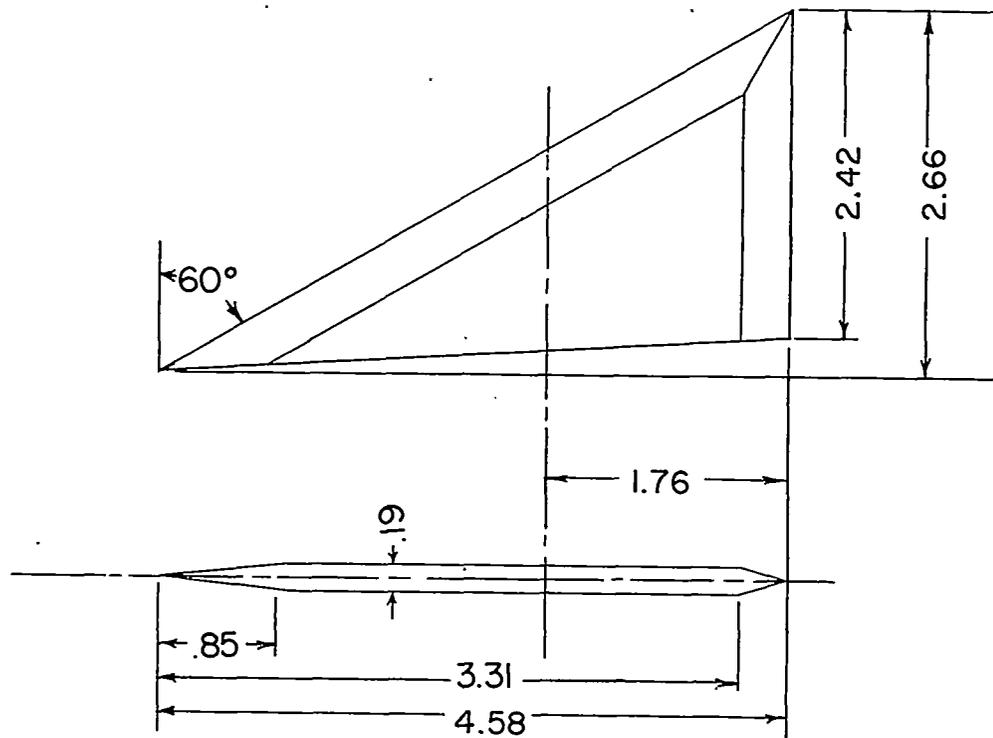


λ/d	Control	S_c/S_w
14.8	60°	0.17
14.8	Large 70°	0.20
14.8	Small 70°	0.05

Figure 2.- Sketches of models. All dimensions in inches.

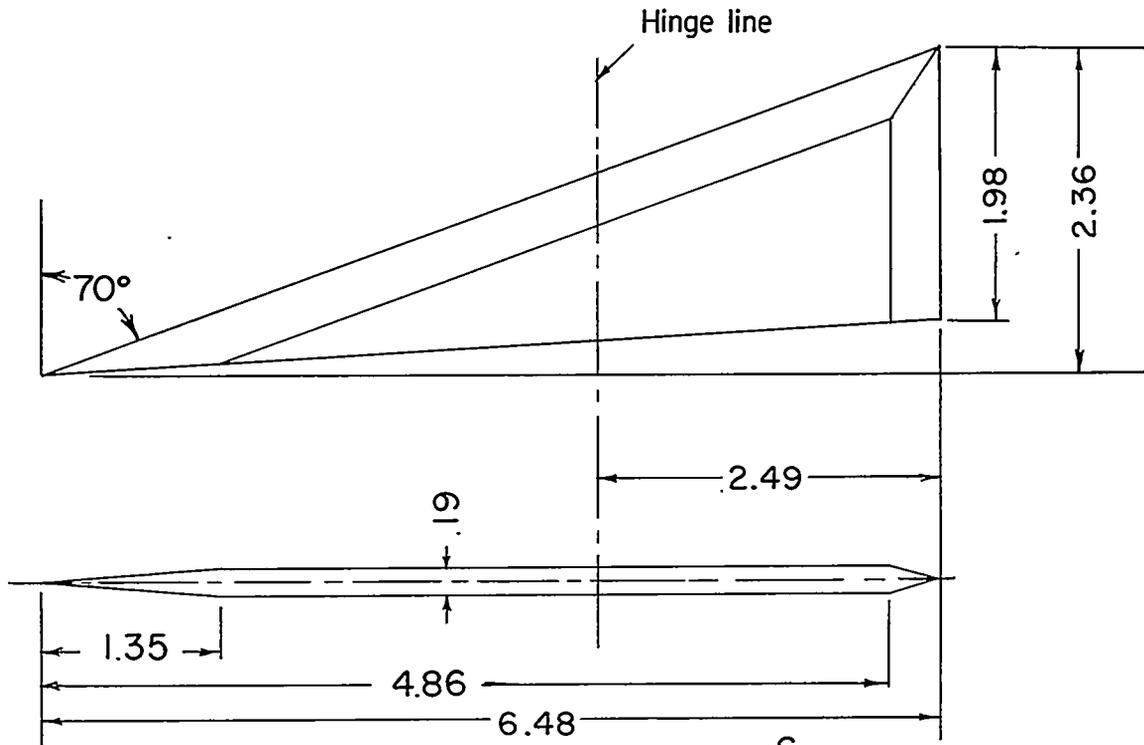


Wing panel

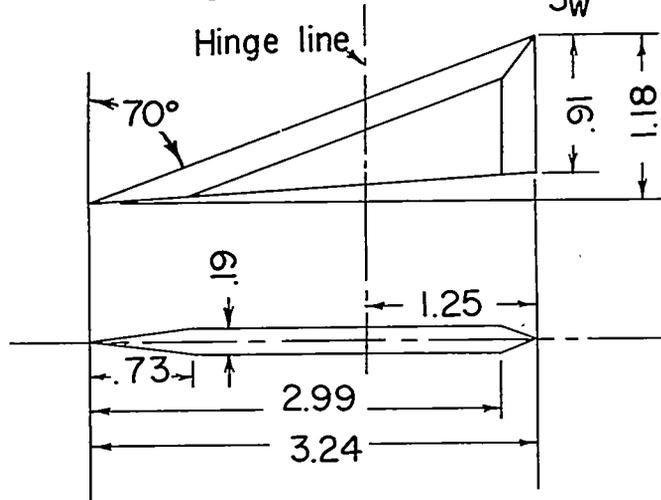


60° delta canard, $\frac{S_c}{S_w} = 0.17$

Figure 3.- Details of wing and canard controls. All dimensions in inches.

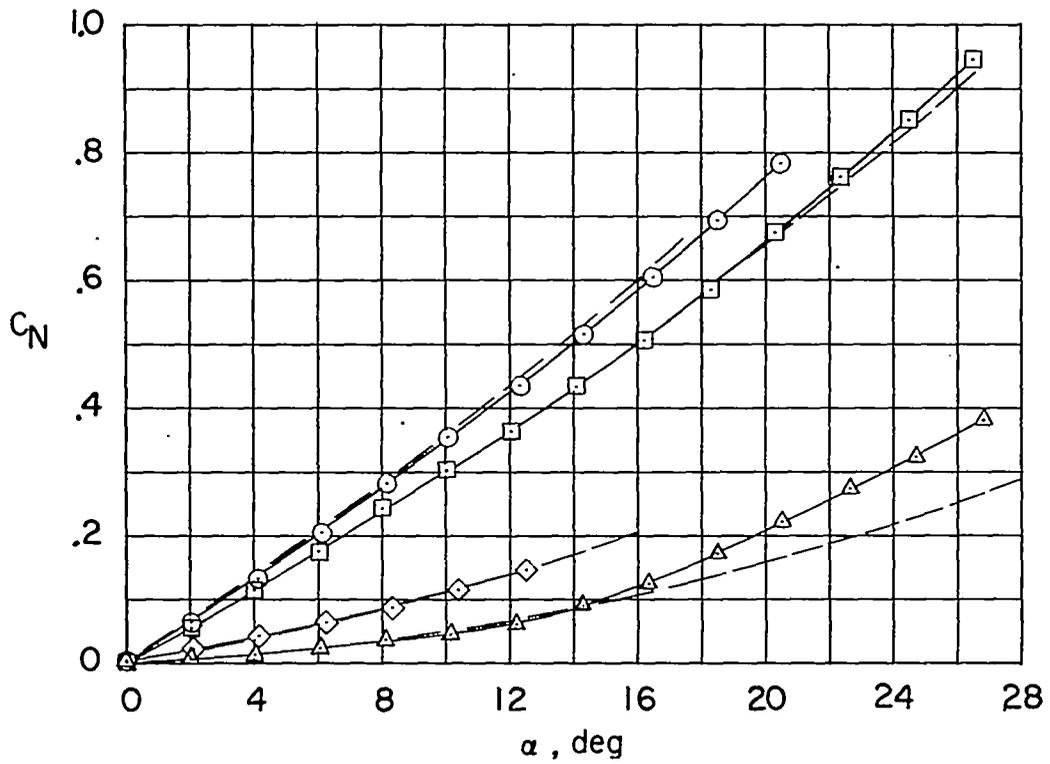
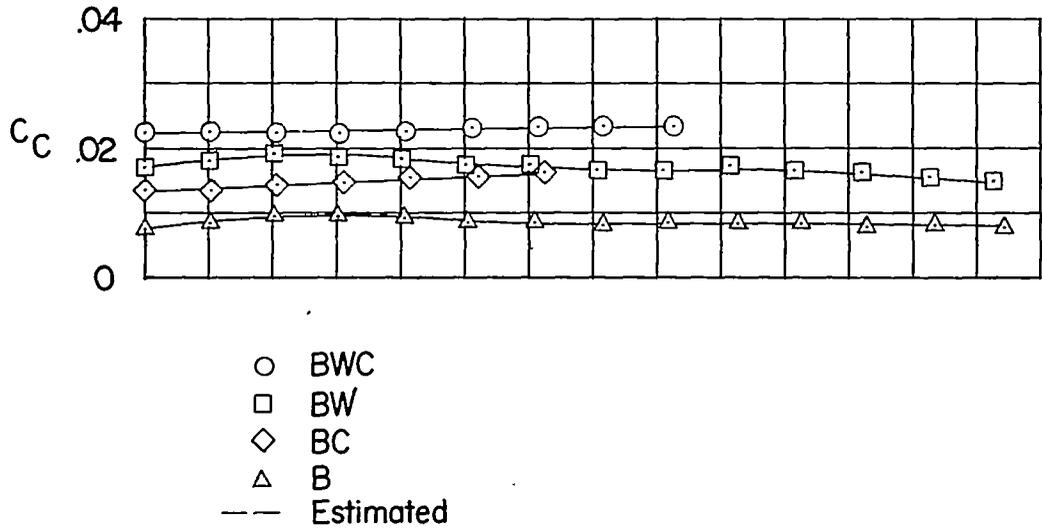


Large 70° delta canard, $\frac{S_c}{S_w} = 0.20$



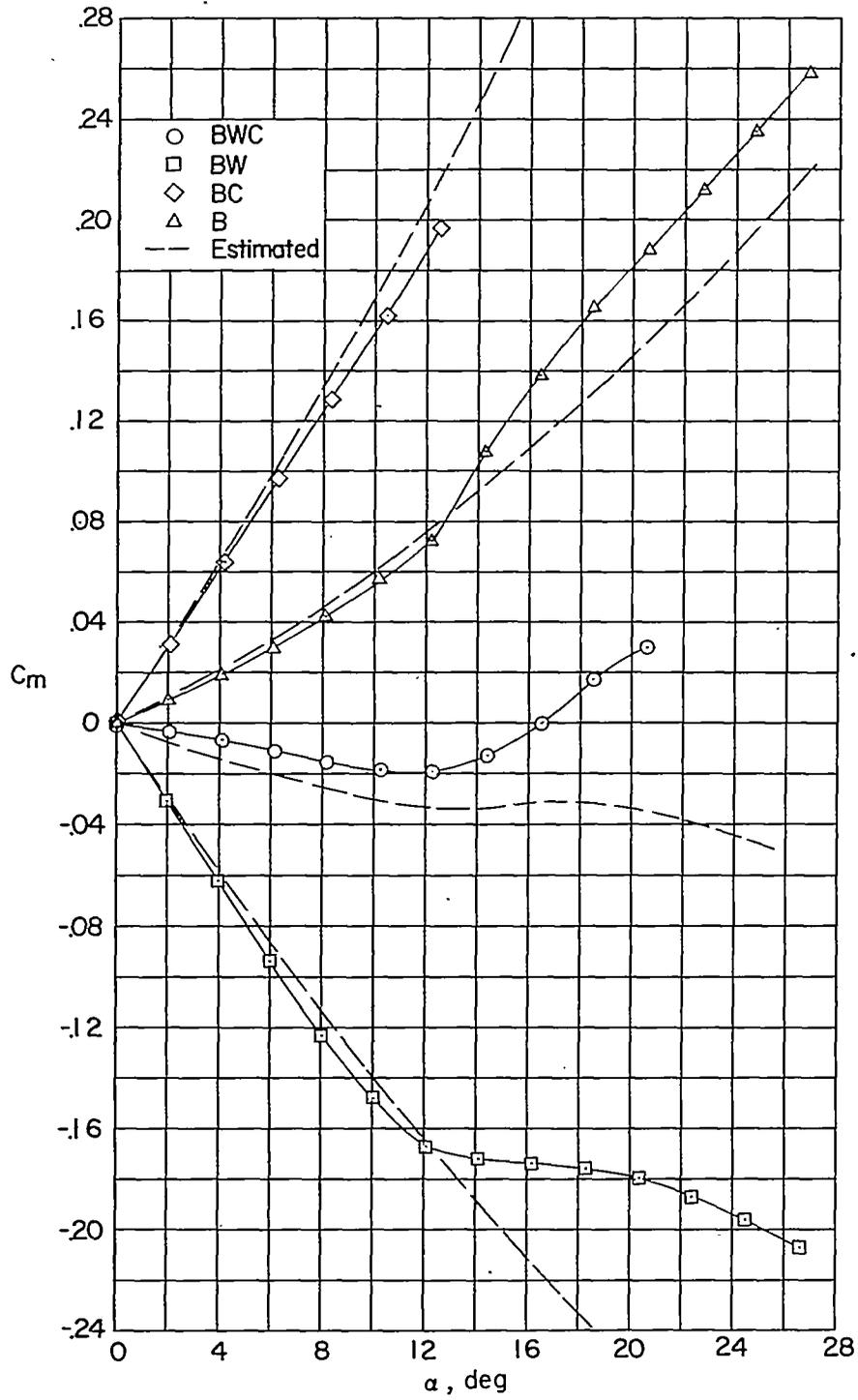
Small 70° delta canard, $\frac{S_c}{S_w} = 0.05$

Figure 3.- Concluded.



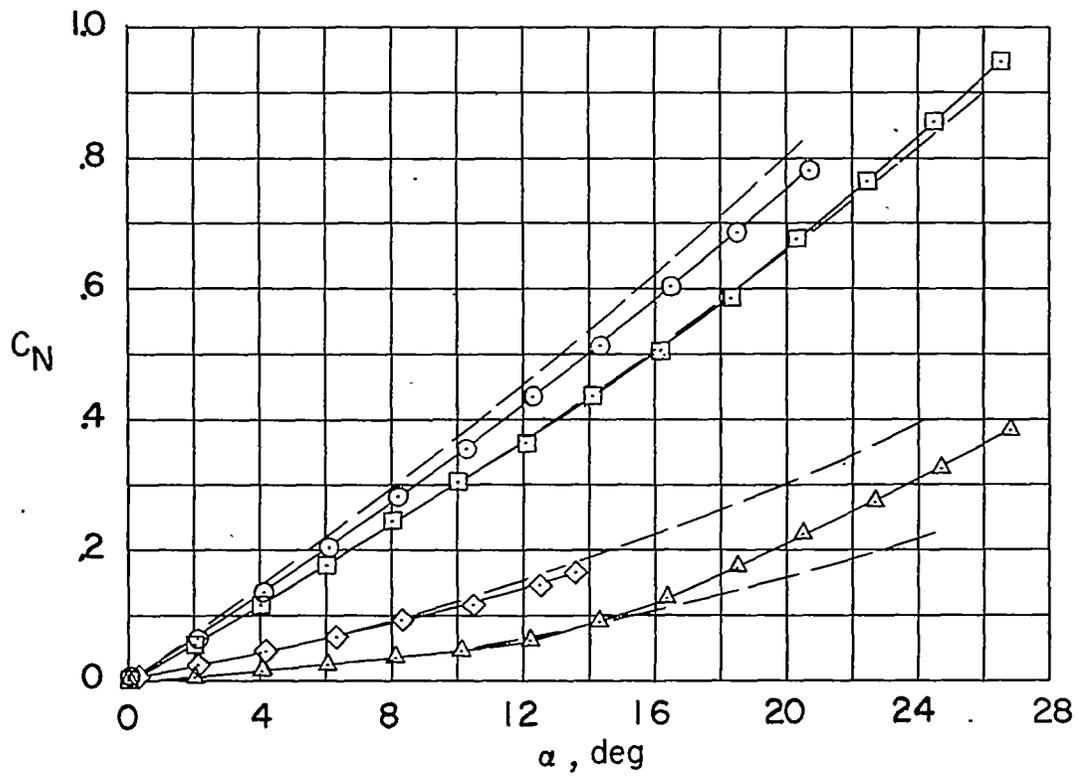
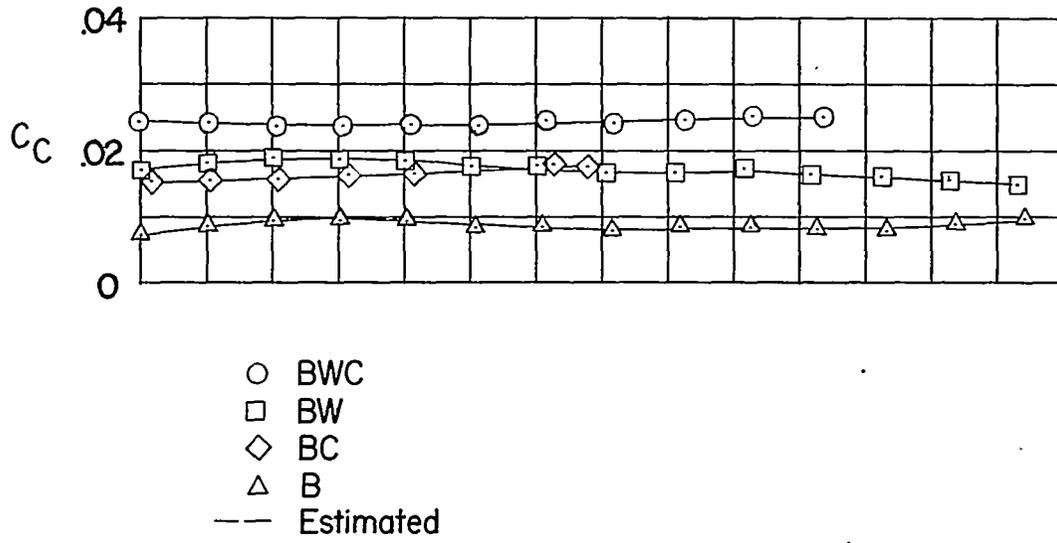
(a) $l/d = 17.7$; large 70° canard control.

Figure 4.- Aerodynamic characteristics in pitch for component parts of various configurations. $\delta_H = 0^\circ$.



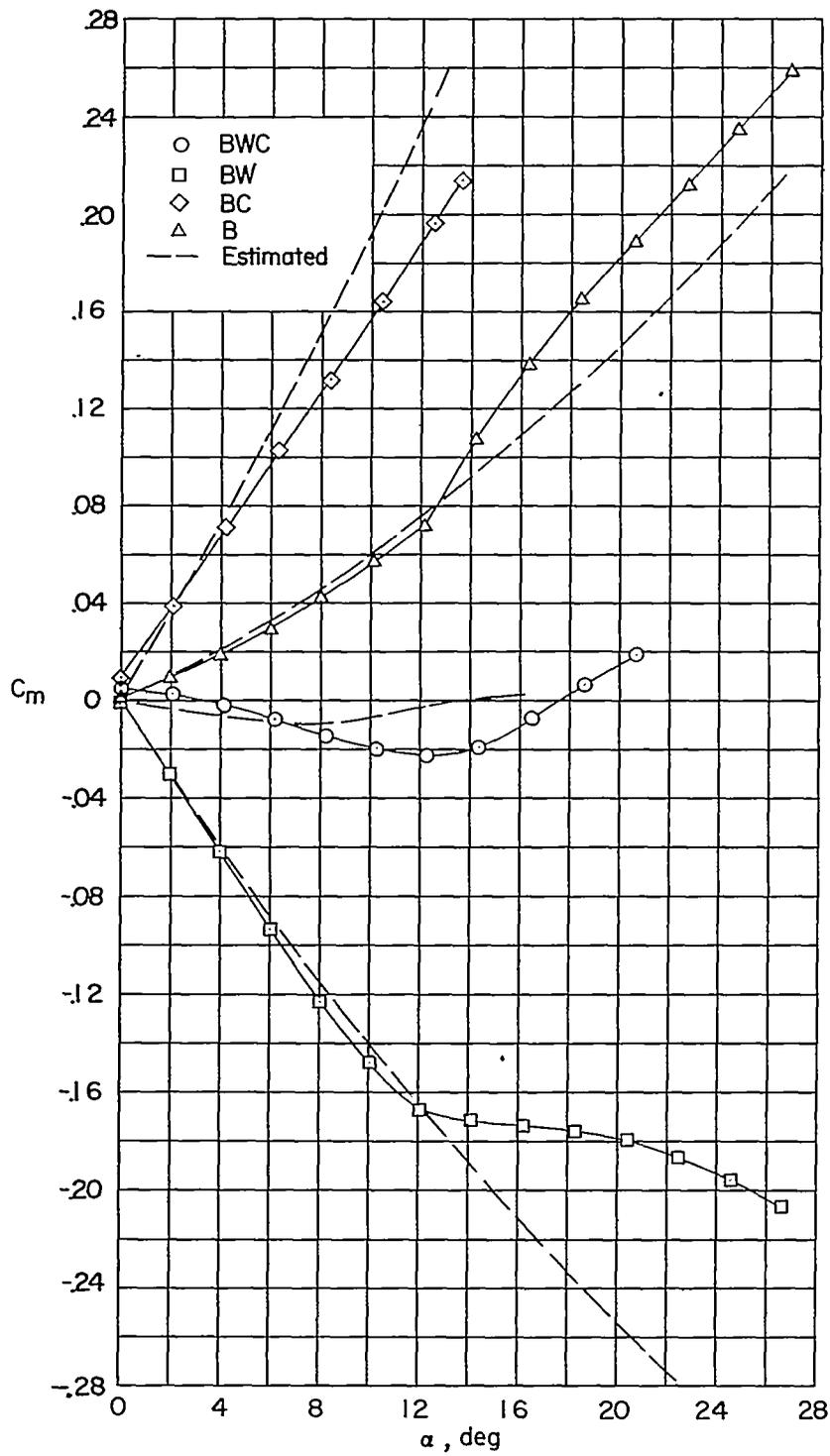
(a) Concluded.

Figure 4.- Continued.



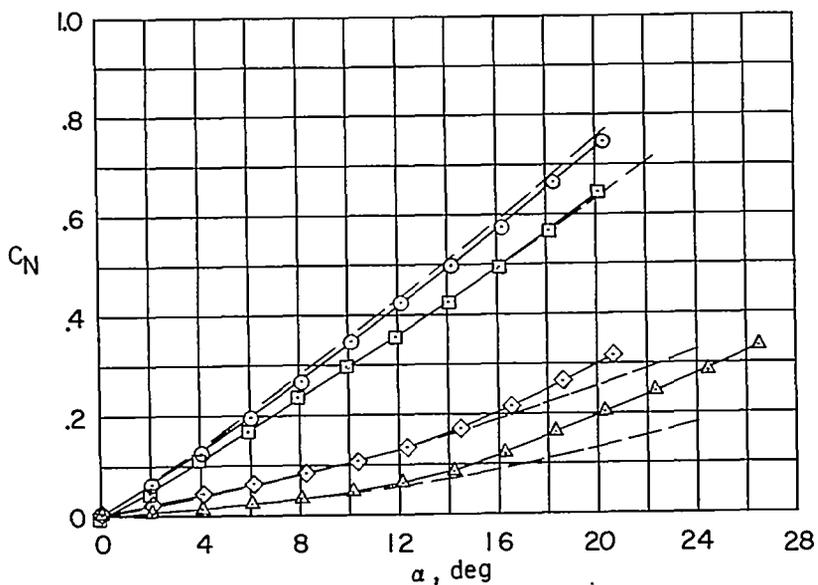
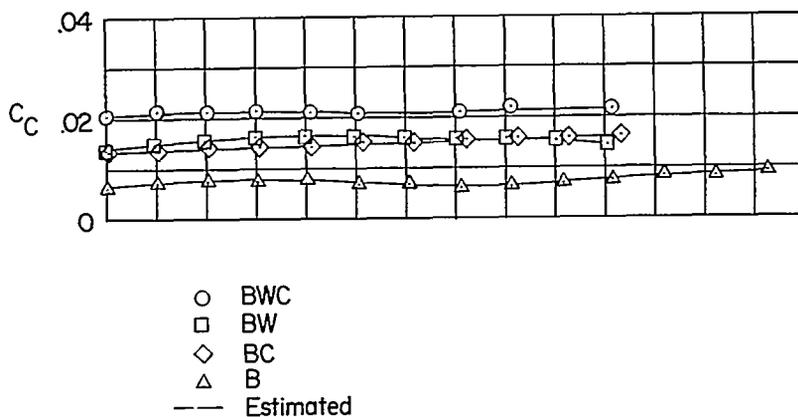
(b) $l/d = 17.7$; 60° canard control.

Figure 4.- Continued.



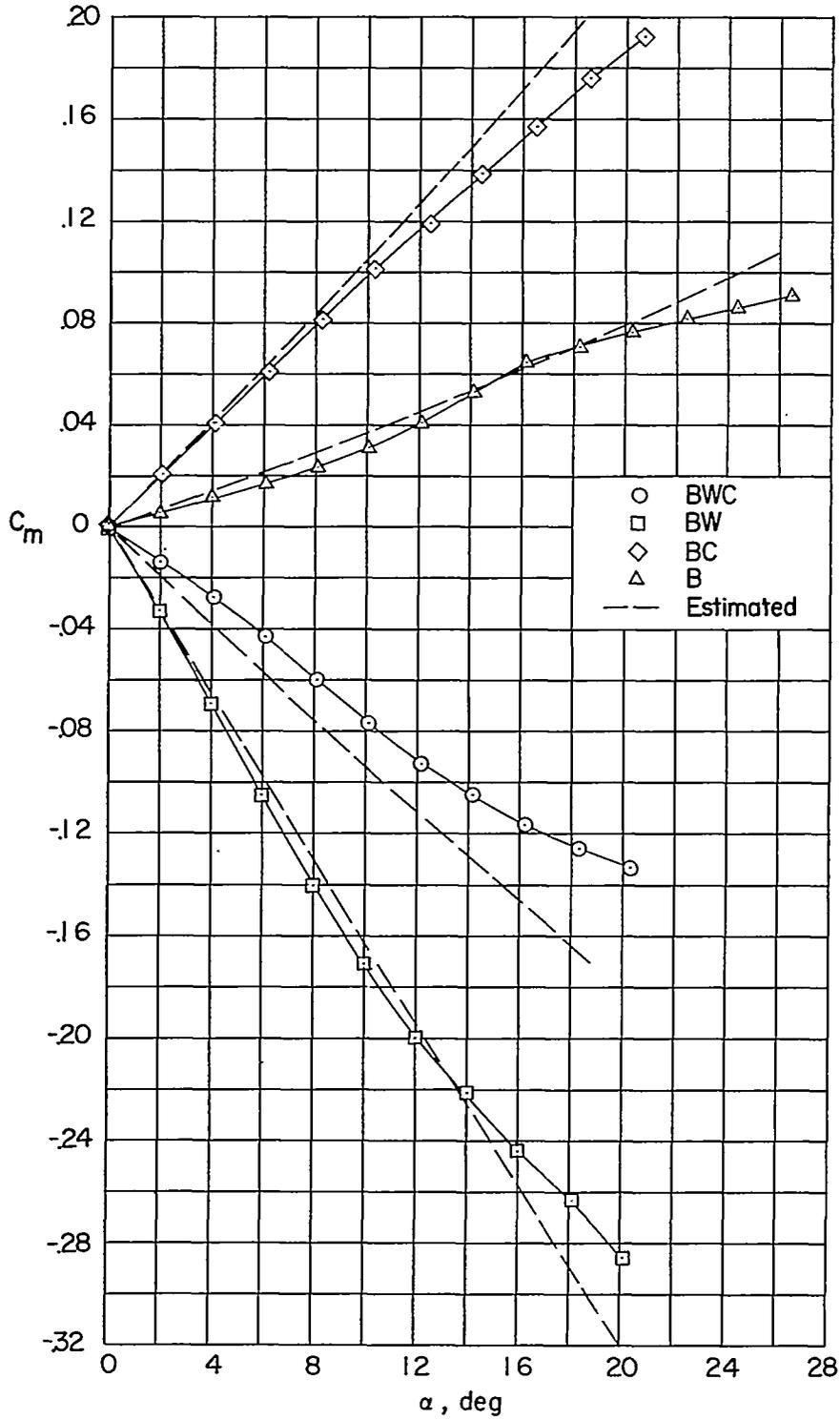
(b) Concluded.

Figure 4.- Continued.



(c) $l/d = 14.8$; large 70° canard control.

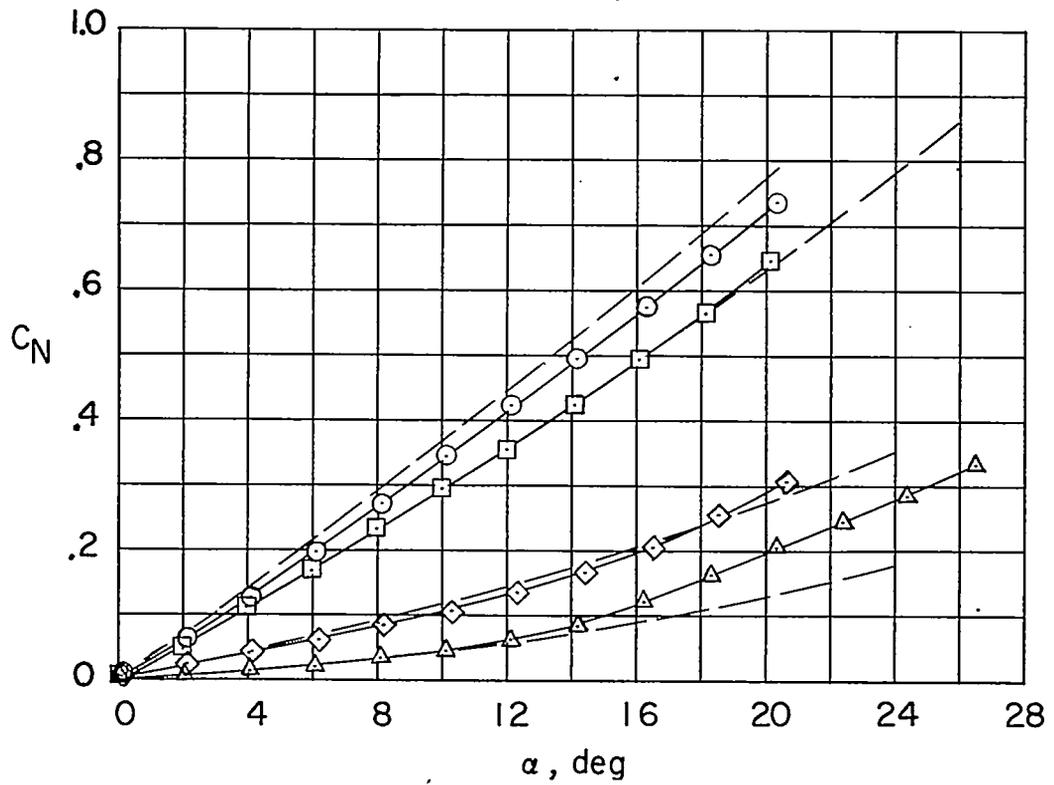
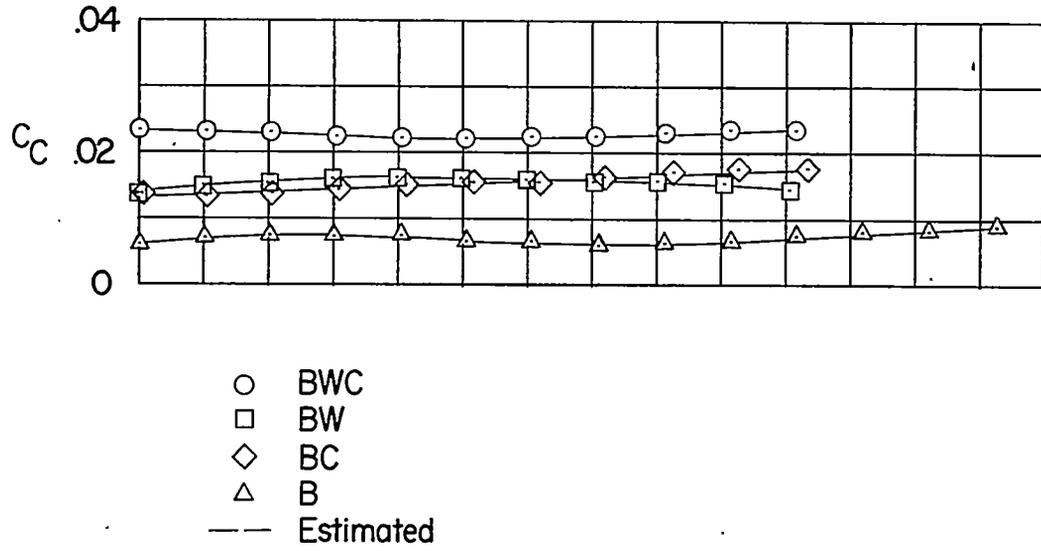
Figure 4.- Continued.



(c) Concluded.

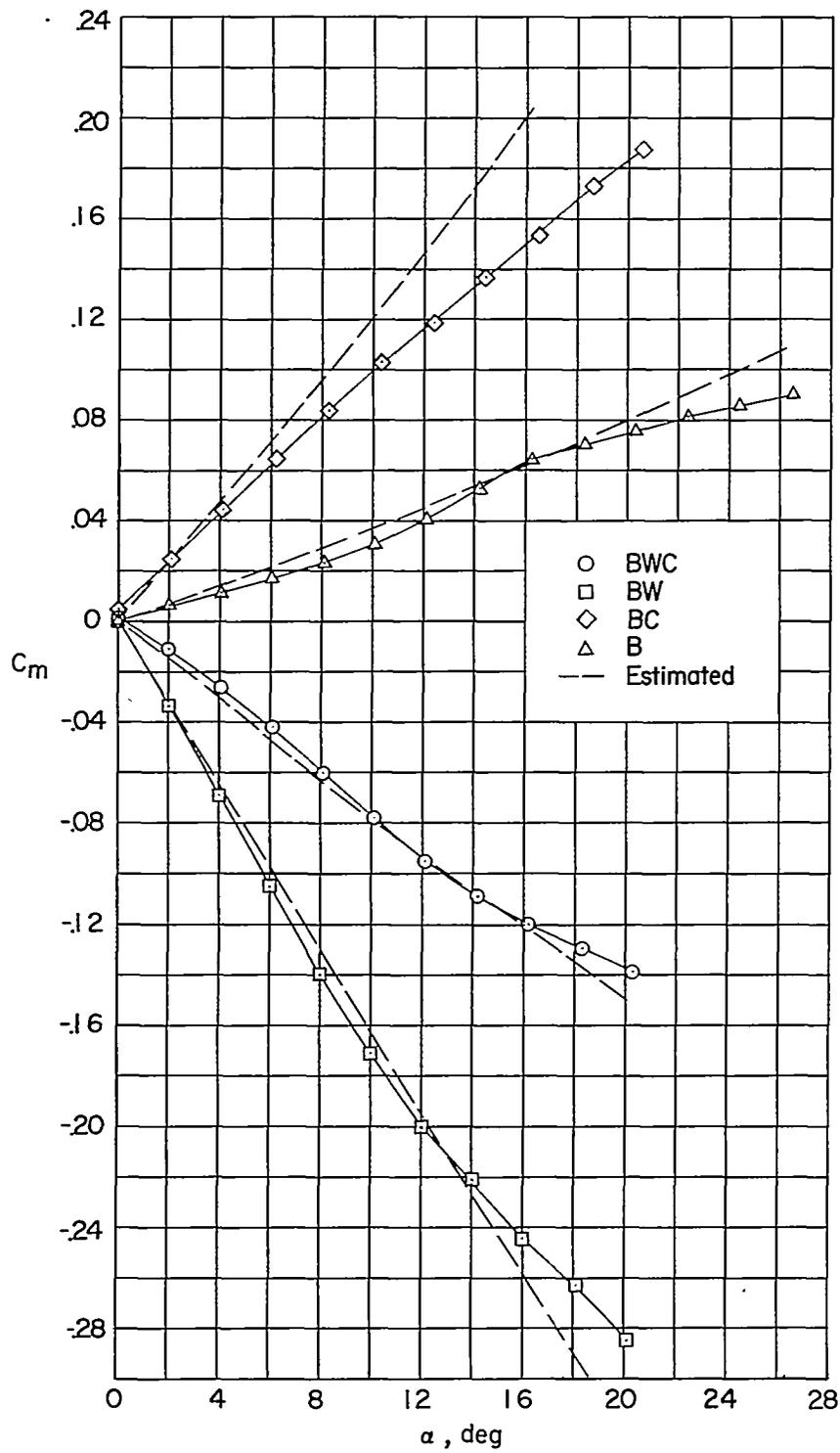
Figure 4.- Continued.

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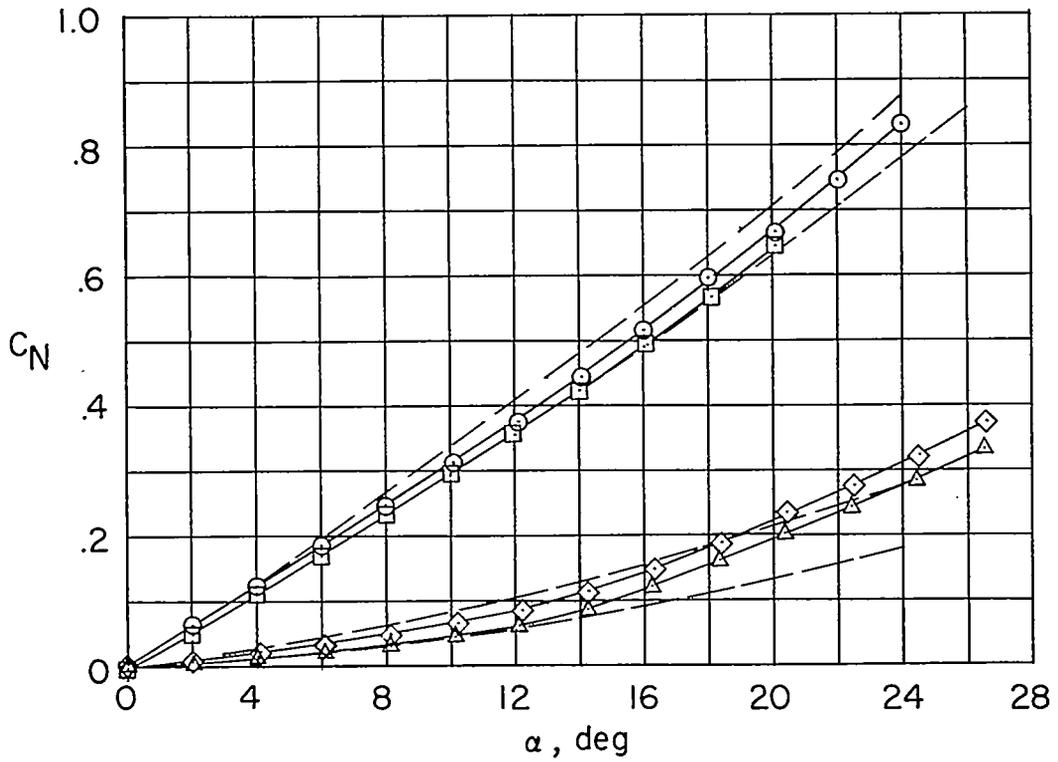
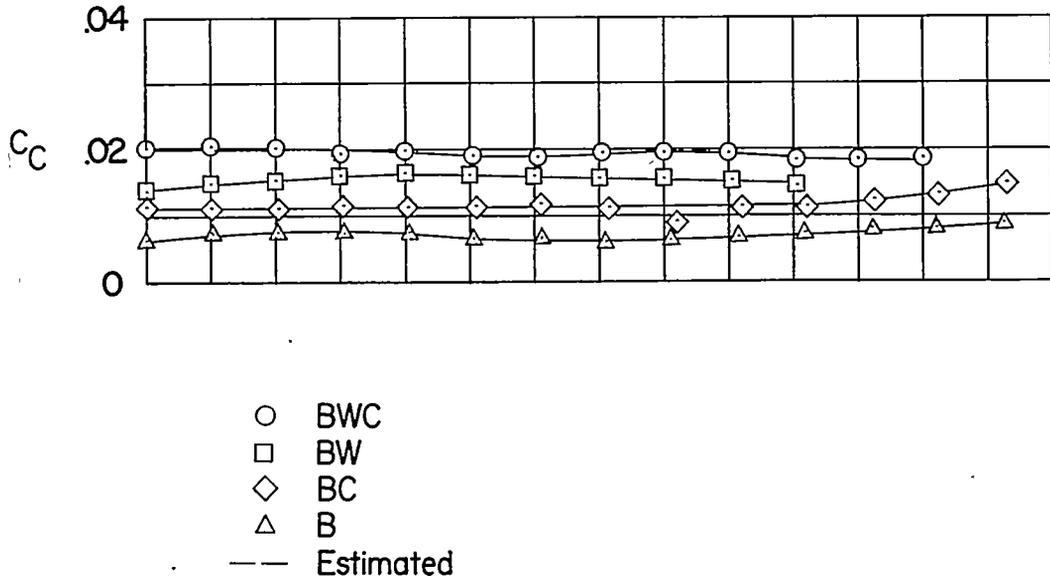
(d) $l/d = 14.8$; 60° canard control.

Figure 4.- Continued.



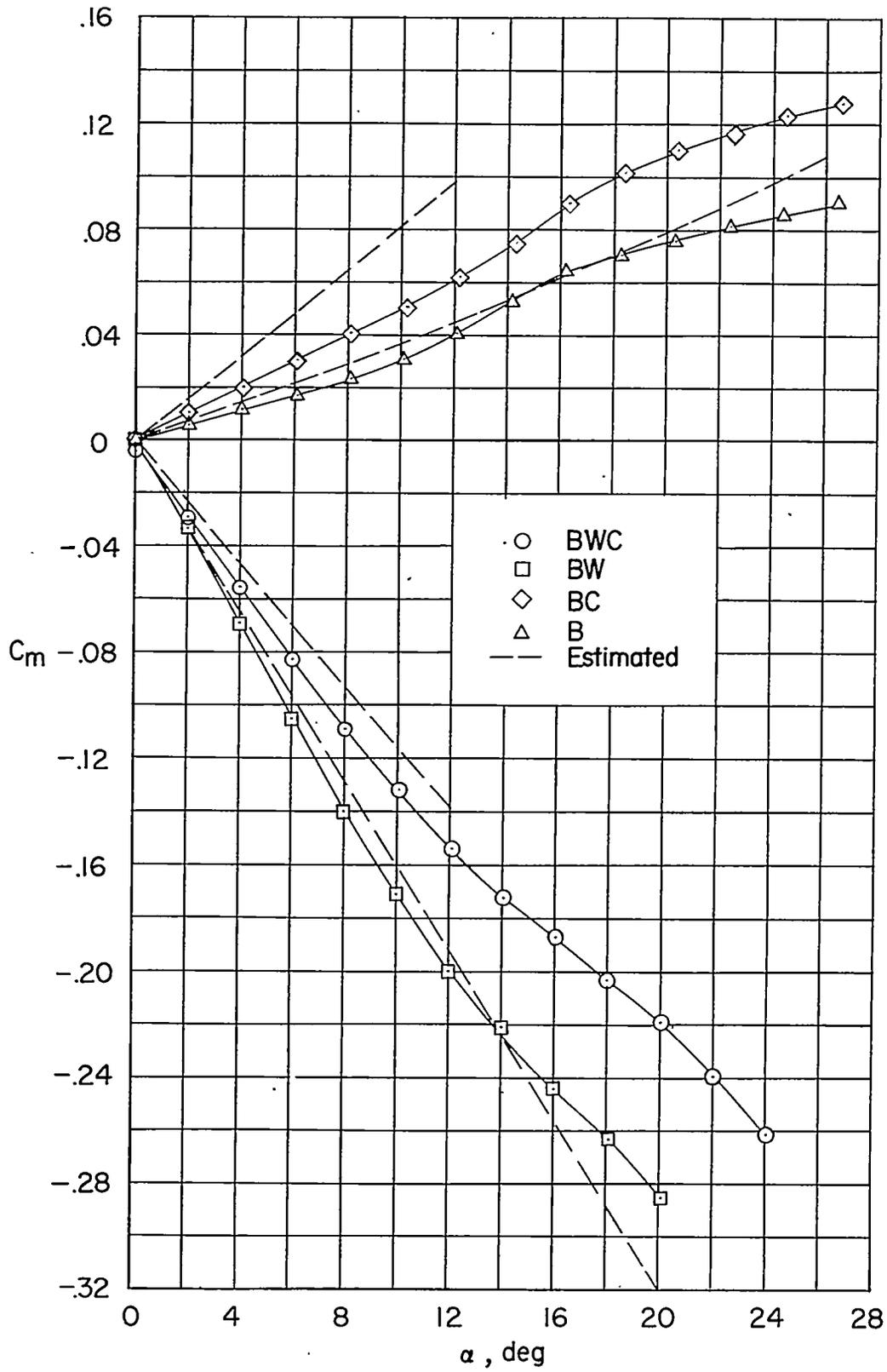
(d) Concluded.

Figure 4.- Continued.



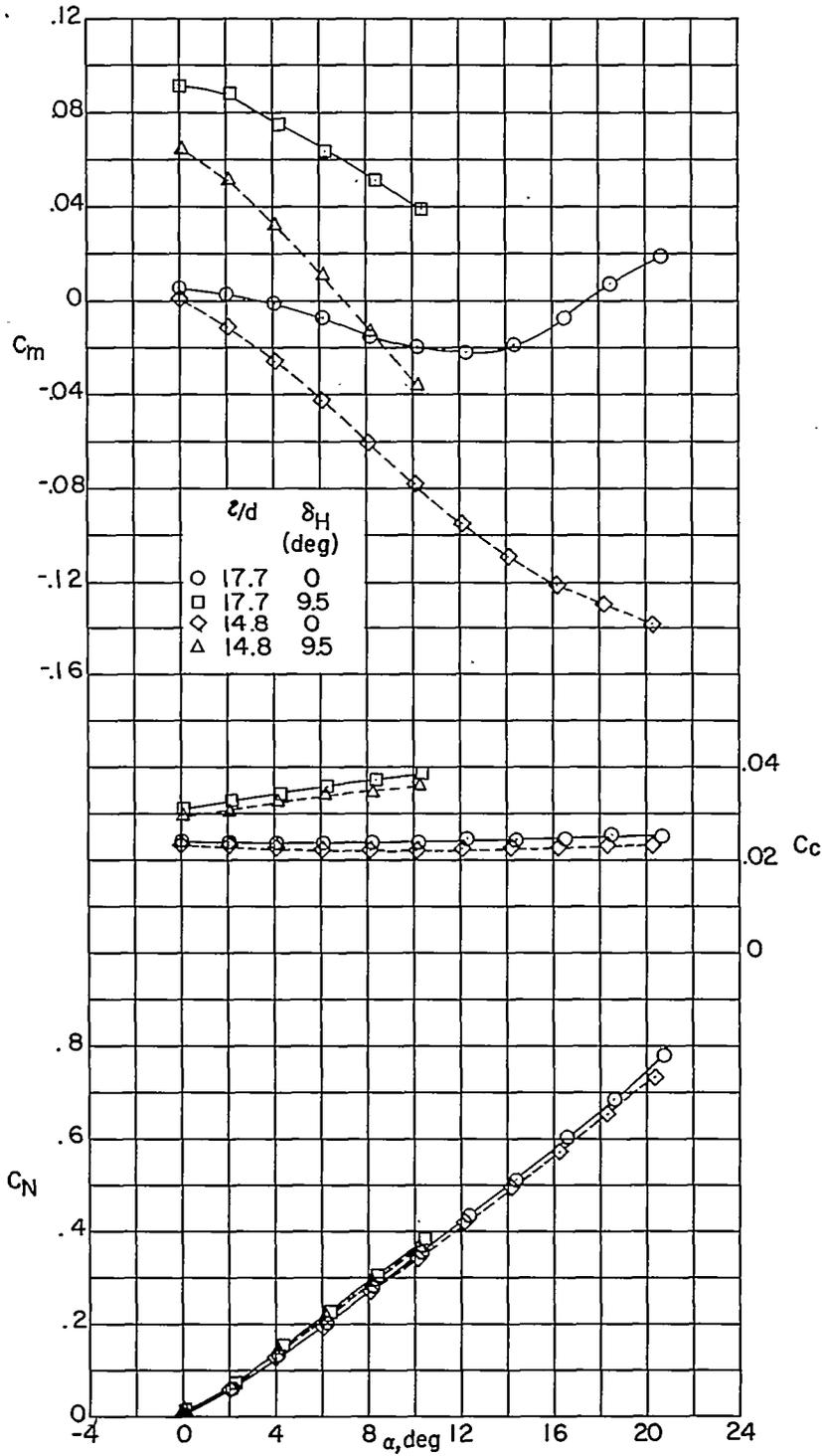
(e) $l/d = 14.8$; small 70° canard control.

Figure 4.- Continued.



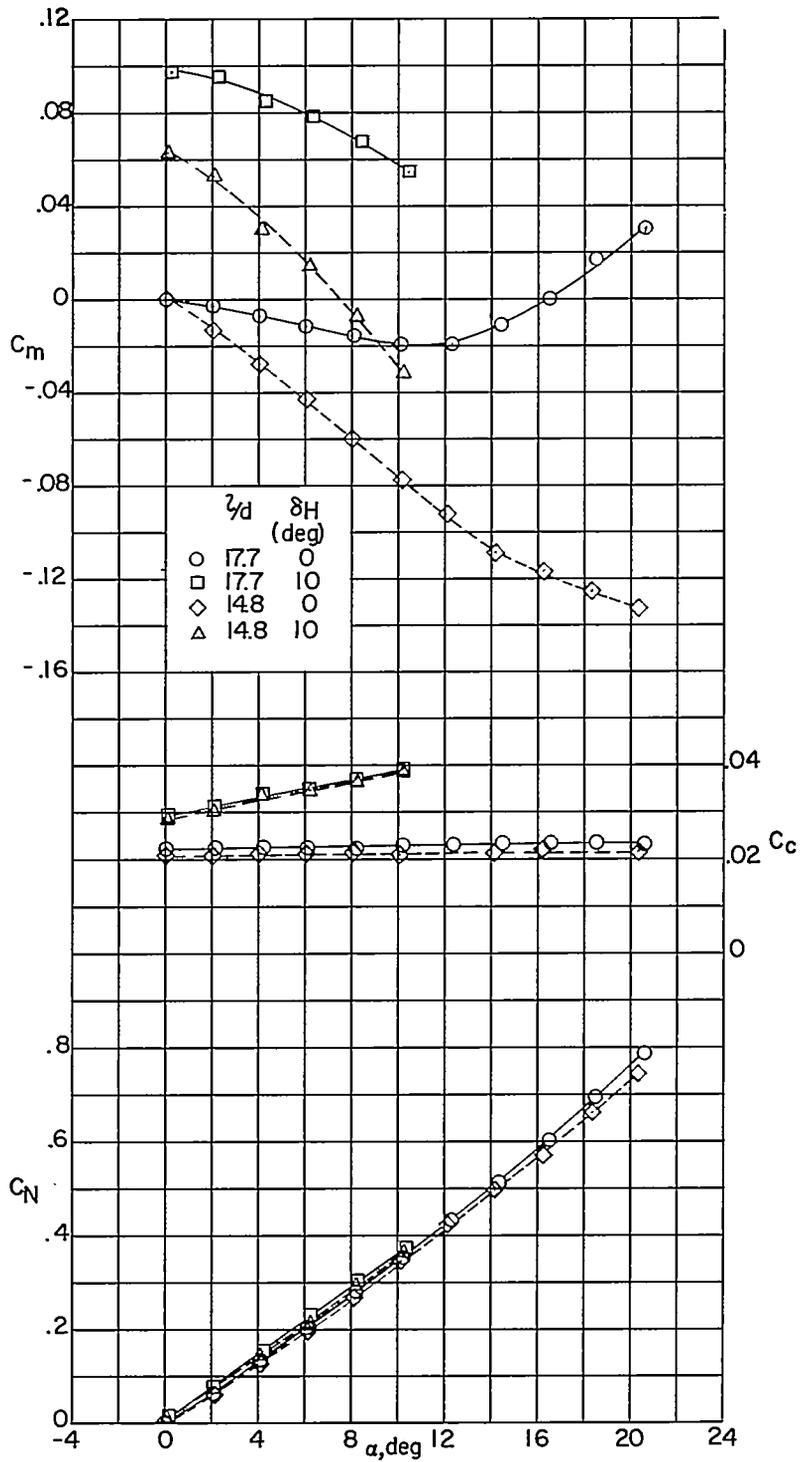
(e) Concluded.

Figure 4.- Concluded.



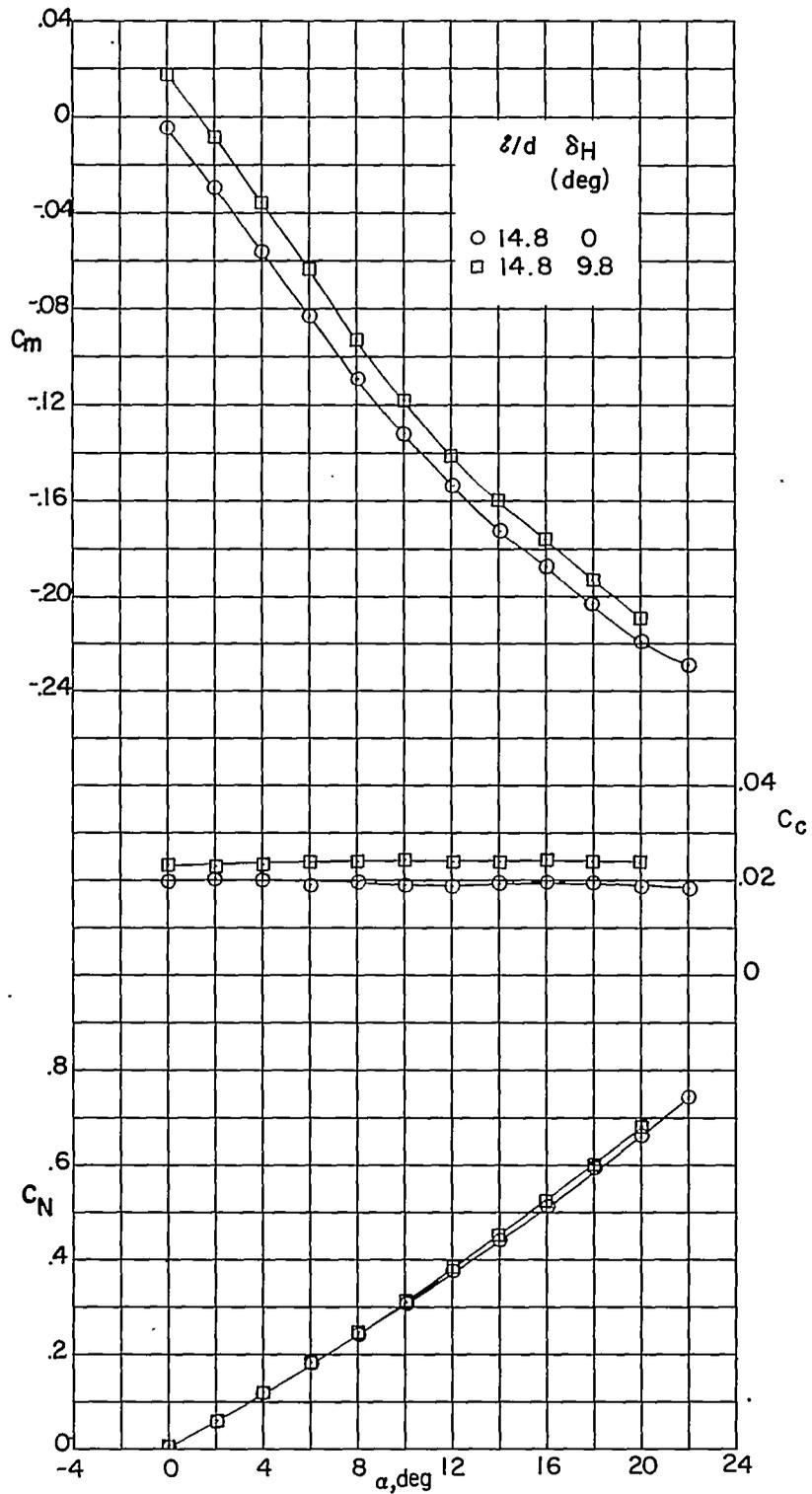
(a) 60° canard control.

Figure 5.- Effect of control deflection on aerodynamic characteristics in pitch. Complete model.



(b) Large 70° canard control.

Figure 5.- Continued.



(c) Small 70° canard control.

Figure 5.- Concluded.

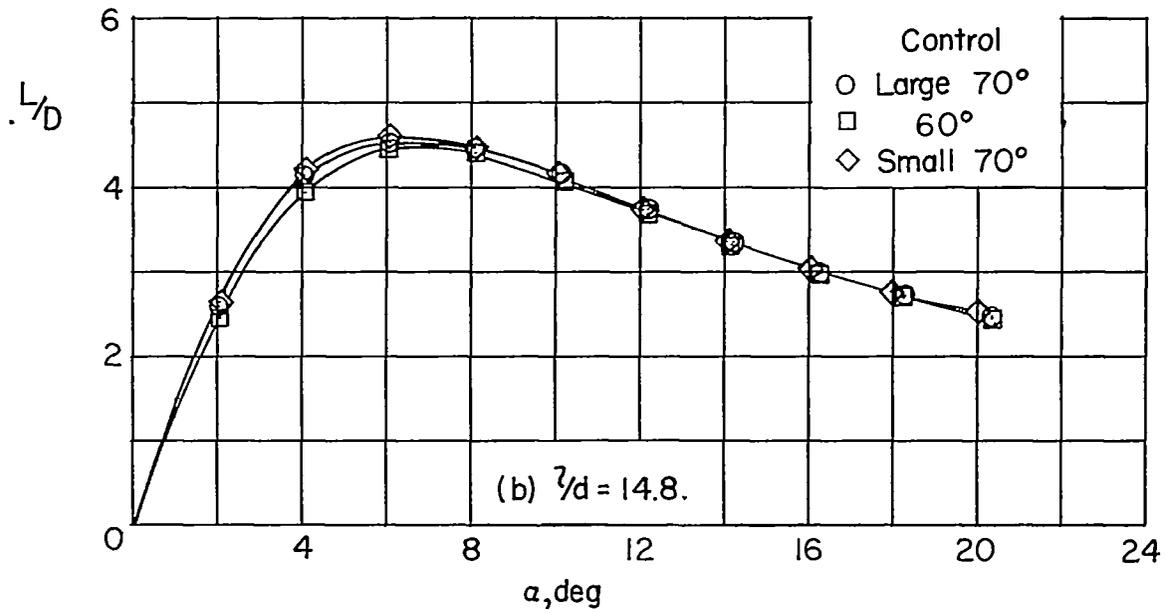
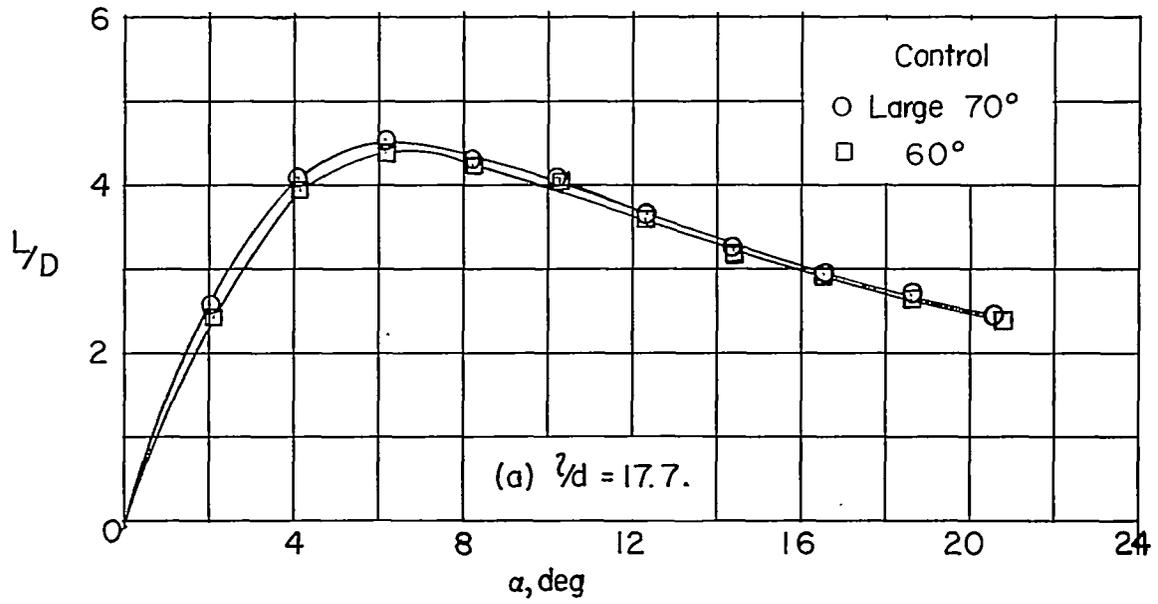


Figure 6.- Lift-drag ratios for the various configurations. $\delta_H = 0^\circ$.

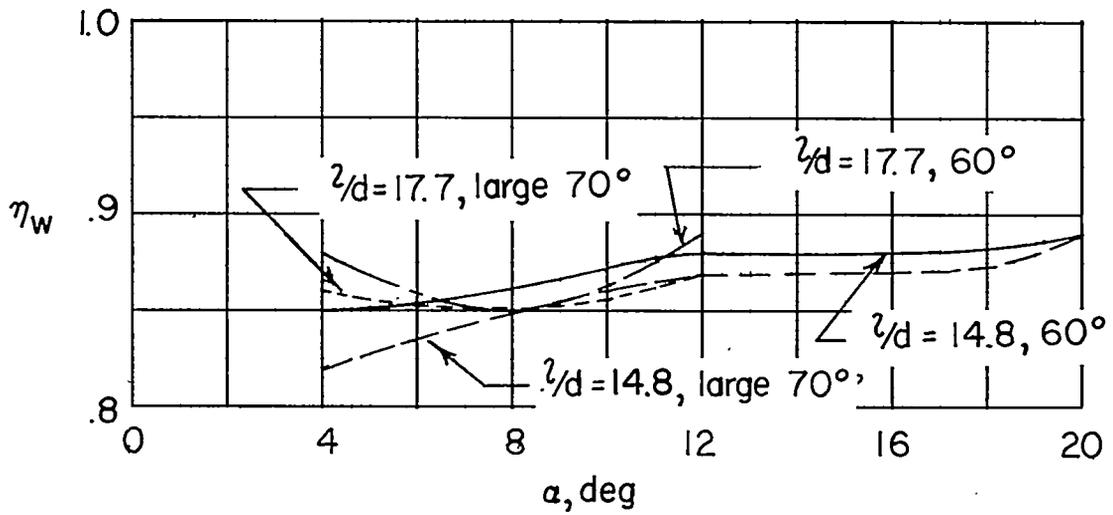
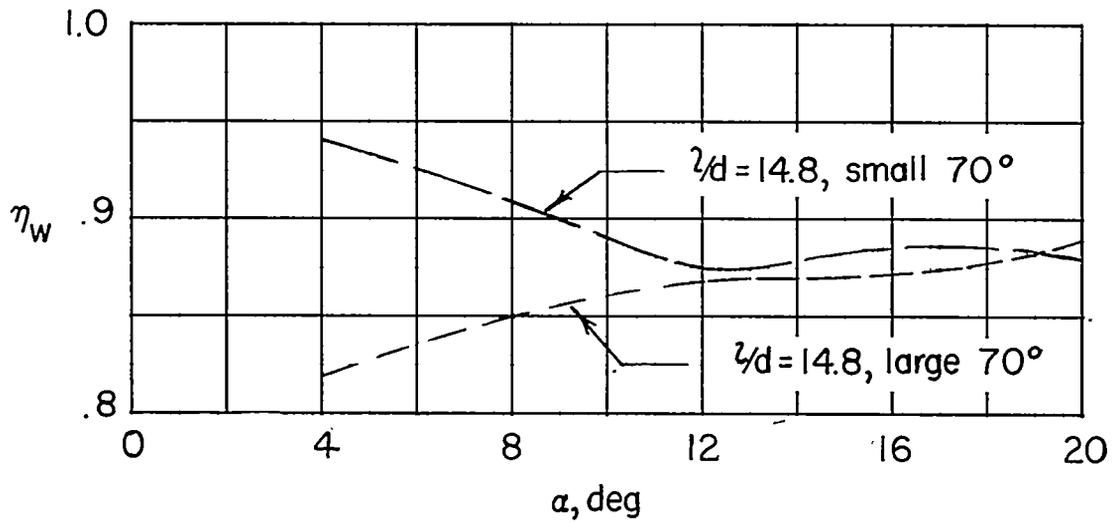


Figure 7.- Wing efficiency factors for the various complete model configurations.

$$\eta_w = \frac{C_{m_{BWC}} - C_{m_{BC}}}{C_{m_{BW}} - C_{m_B}}$$

Estimate	Experiment	l/d	Control	S_c/S_w
○	————	17.7	Large 70°	0.20
□	-----	17.7	60°	0.17
◇	-----	14.8	Large 70°	0.20
△	-----	14.8	60°	0.17
▽	-----	14.8	Small 70°	0.05

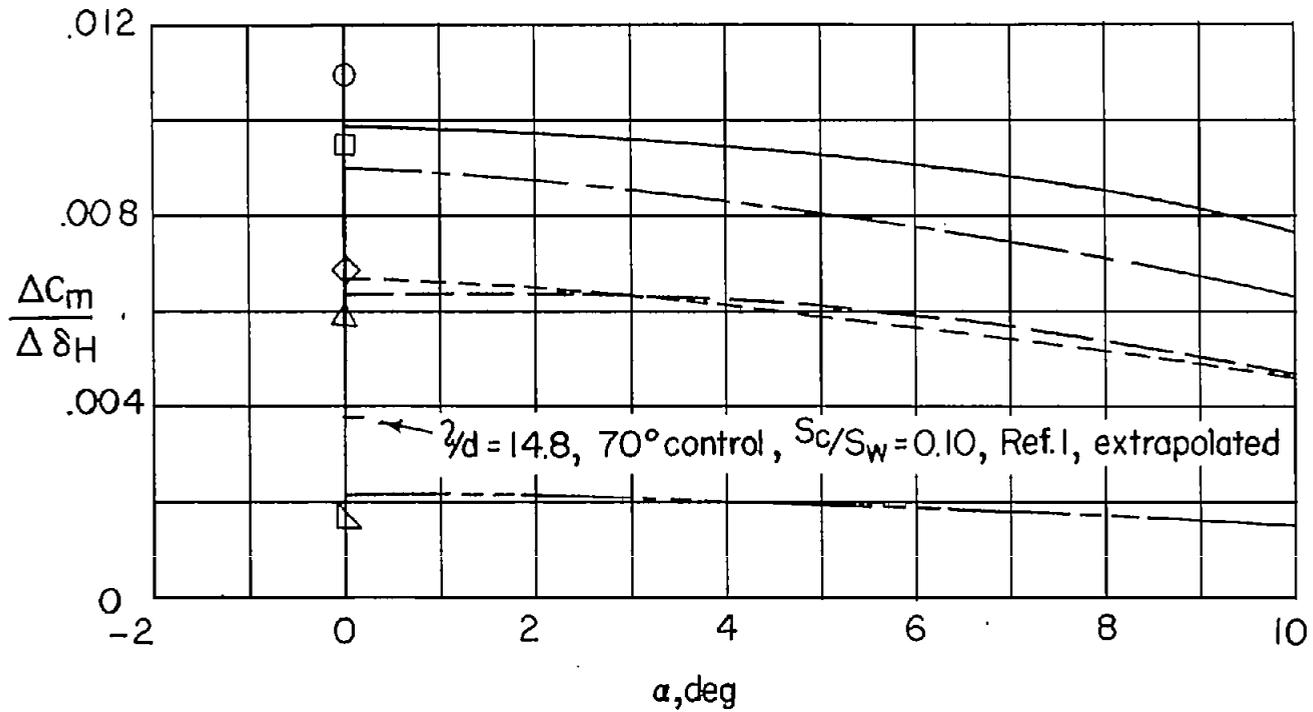


Figure 8.- Pitching-moment increment due to control deflection. Complete models.

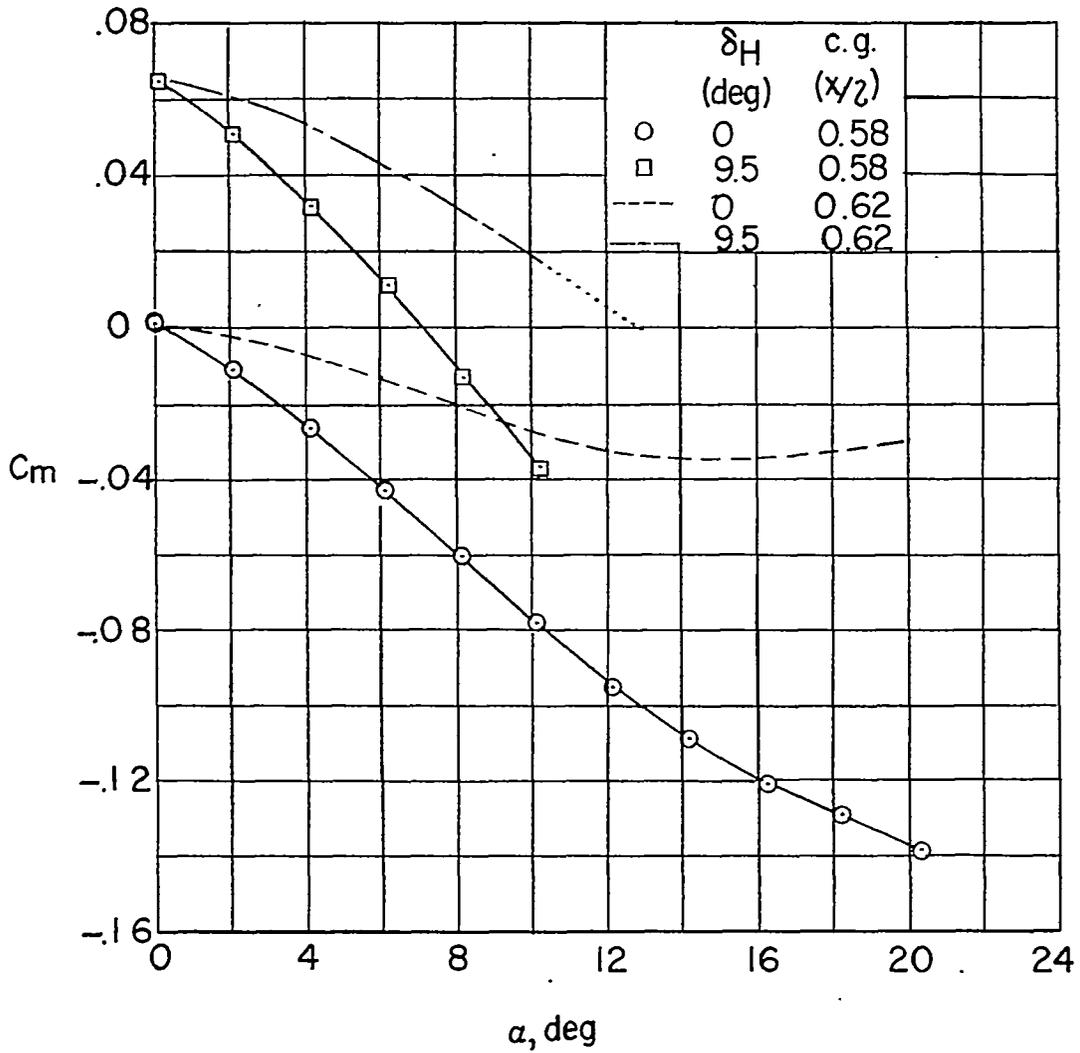


Figure 9.- Effect of center-of-gravity location on the pitching-moment characteristics. $l/d = 14.8$; 60° canard control.

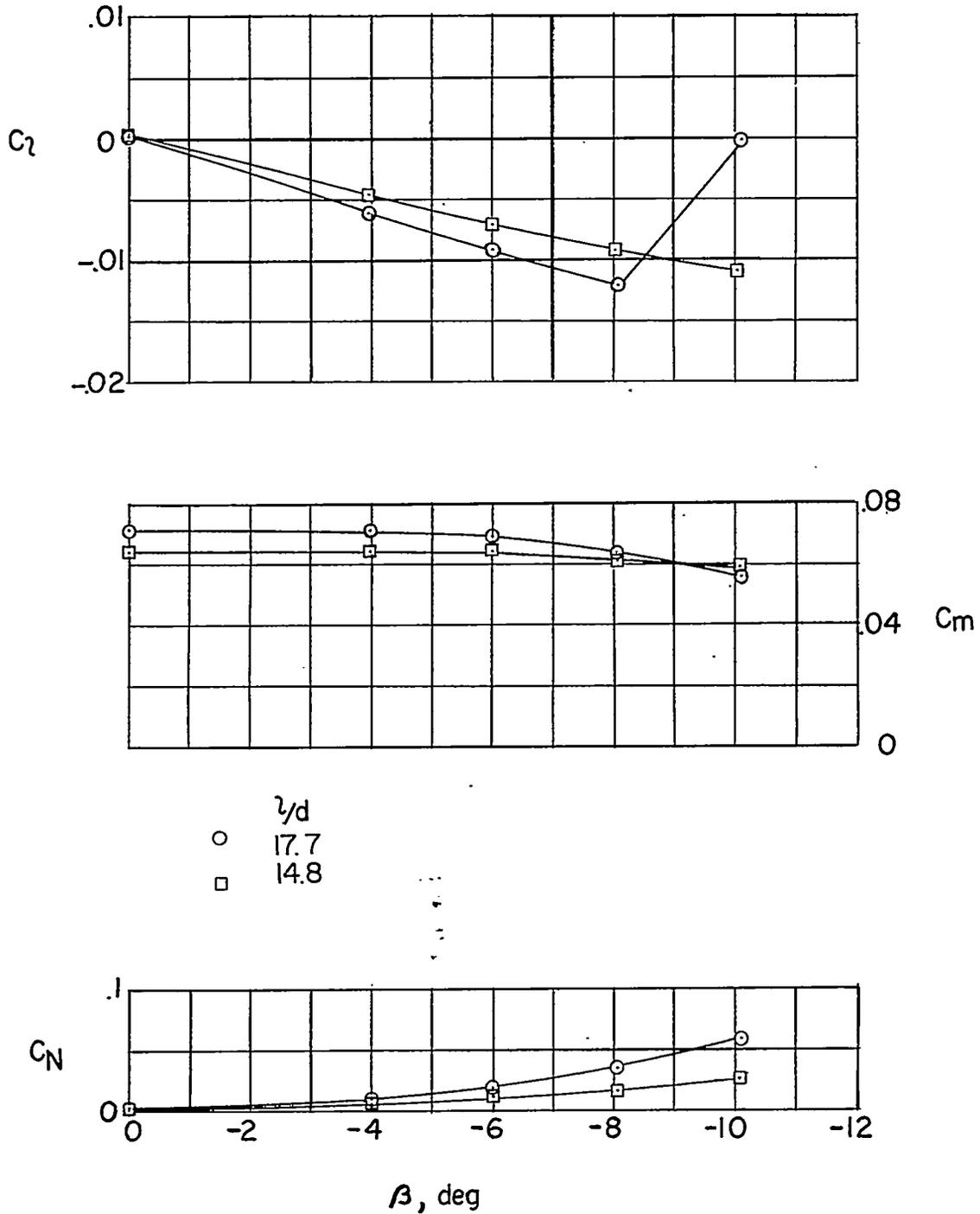


Figure 10.- Effect of body length on the induced lateral characteristics resulting from control deflection. Model with large 70° canard control; $\delta_H = 10^\circ$.